Renovation of the CBR Design Procedure

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RENOVATING THE CBR THICKNESS DESIGN PROCEDURE

REPORT 1
UNDERSTANDING, SCRUTINIZING AND REVAMPING THE CBR THICKNESS DESIGN METHODOLOGY
Reference:
CROW. “Guideline on PCN Assignment in the Netherlands”
CROW-report 05-06, CROW, Galvanistratt 1, NL-6717 AE Ede,
The Netherlands, August 2005

“It is now widely recognized that the US Corps of Engineers’
CBR method cannot adequately compute or predict pavement
damage caused by new large aircraft.”
Chronological Order Of Important Events

- May 1941—XB-19 Rolled out of hanger and broke through apron
- June 1941—General Brett demanded all military airstrip be of PCC
- July 1941—General Reybold rules that Engineers would be responsible for pavement design
- October 1941—Investigative effort started with overall objective to write new chapter in civil engineering
- Early 1942—Colonel Stratton calls for O. James Porter; adopts CBR procedure; starts field investigations
- April 1942—Course on CBR conducted by Porter
- April 1943—Flexible Pavement Laboratory established at Vicksburg, MS
- 1945-1946—Stockton Test No. 2
- January 1949—ASCE published Proceedings of symposium on CBR procedure
- 1949—Thickness reduction factor proposed to consider less than capacity operations
- 1955—Classical form of CBR equation developed with ESWL based on deflection
- 1967-1969—Multi-wheel Heavy Gear Load test section constructed and tested
- 1970—Alpha factors introduced to consider traffic volume and gear type
- 1994—Temporary reduction in Alpha factor granted for B-777
- 2005—Renovated CBR design procedure proposed

Classical CBR Equation

\[ t = \alpha \cdot \sqrt{\frac{ESWL}{8.1 \cdot CBR}} - \frac{A}{\pi} \]

Rearranging the Equation

\[ \frac{t}{r} = \sqrt{\alpha^2 \cdot \frac{\pi \cdot p}{\beta \cdot CBR} - \alpha^2} \]
Development of CBR Equation

The general stress equation is:

$$\sigma_i = \frac{n \cdot P}{2 \cdot \pi \cdot R^2} \cos^* \phi$$

Under the Center of a Tire

$$\sigma_i = \sigma_0 \cdot 1 - \frac{1}{\left(1 + \left(\frac{t}{r}\right)^2\right)^{n}}$$

For $n = 2$ the stress equation is:

$$\sigma_i = \sigma_0 \cdot \frac{1}{1 + \left(\frac{t}{r}\right)^2}$$

The original California criteria was:

$$t = k \cdot \sqrt{P}$$

The original criteria can be expressed as:

$$\left(\frac{t}{r}\right)^2 = k^2 \cdot P \cdot \pi$$
Substituting for \( t/r \)

\[
\sigma_i = \frac{1}{\pi \cdot \left( k^2 + \frac{1}{\pi \cdot p} \right)}
\]

Rearrange and divide by CBR

\[
\frac{\pi \cdot \sigma_i}{CBR} = \frac{1}{CBR \cdot \left[ k^2 + \frac{1}{\pi \cdot p} \right]}
\]

<table>
<thead>
<tr>
<th>Table 2.4-1: K Values for CBR Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>(from &quot;Mathematical Expression of the CBR Relations, COE Technical Report No. 3-441, November 1956&quot;)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Values of D × CBR</th>
<th>Values of D = K² + 1/(p²π²)</th>
<th>Values of D = CBRCBR</th>
</tr>
</thead>
<tbody>
<tr>
<td>200-psi</td>
<td>100-psi</td>
<td>200-psi</td>
</tr>
<tr>
<td>CBR</td>
<td>CBR Values</td>
<td>CBR Values</td>
</tr>
<tr>
<td>2</td>
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<td>0.199</td>
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<td>4</td>
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<td>0.093</td>
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<td>0.087</td>
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<tr>
<td>20</td>
<td>0.076</td>
<td>0.081</td>
</tr>
</tbody>
</table>

Changing the of the CBR Equation
From the table of data the constant is found to be:

\[ \beta_1 = \frac{1}{CBR \cdot \left[ k^2 + \frac{1}{\pi \cdot p} \right]} = \frac{1}{.123} = 8.1 \]

Originally this constant was for capacity operations
Currently this constant is for 10000 coverages (Alpha = 1)
Changing the of the CBR Equation

CBR equation in terms of a factor $\beta$ such that:

$$\frac{t}{r} = \sqrt{\alpha^2 \cdot \frac{\pi \cdot p}{\beta \cdot CBR}} - \alpha^2$$

Where:

$$\beta = \frac{\sigma_f \cdot \pi}{CBR}$$

For a single wheel Beta can be related to Alpha by:

$$\beta = \frac{\pi \cdot p}{CBR \cdot \left[ \frac{\pi \cdot p \cdot \alpha_1^2}{8.1 \cdot CBR} - \alpha_1^2 + 1 \right]}$$
Stress Distribution for the Center Line Under Circular Load

\[ \sigma_z = \sigma_0 \cdot \left[ 1 - \frac{1}{\sqrt{1 + \left( \frac{a}{z} \right)^2}} \right] \]  

Equation 20.1

For \( n = 3 \) equation 20.1 becomes the Boussinesq equation.
Changing the of the CBR Equation

Relationship Between Concentration Factor and CBR

Stress concentration factor

Log CBR
In the Final Form

- Design Criteria will be in terms of Beta
- Beta will be computed for each aircraft based on a concentration factor
- Concentration factor will be a function of Design CBR
- Traffic volume in terms of coverages will be a function of aircraft operations, number of tires, gear arrangement, and depth

Beta Criteria based on $n = 2$

- FAA TEST FAC. 5-WHEEL
- FAA TEST FAC. 4-WHEEL
- MWHGL 747
- MWHGL C-5
- All single wheel data
- Fit through data

Equations:

$$a = 1.7782$$
$$b = 0.5031$$
$$c = 0.2397$$
Beta is defined as:

\[
\beta = \frac{\sigma_f \cdot \pi}{CBR}
\]

Final Formulation for Single-Wheel

\[
\frac{t}{r} = \frac{1}{\left(1 - \frac{1}{\frac{\beta \cdot CBR_{Design}}{\pi \cdot p}}\right)^2} - 1
\]
Multi-Wheel Gear

\[
\sigma_z = \sum_{i=1}^{\text{wheels}} \frac{n_i \cdot P_i}{2 \cdot \pi \cdot R^2} \cdot \cos^n \theta
\]

Equation 13.1

Where:
- \( n \) = the concentration factor
- \( R \) = the distance from the load to the general point
- \( \theta \) = the angle from the vertical to point
- \( P \) = the applied point load

REALITY CHECK FOR REFORMULATED EQUATION (BETA = 8.1)

- F-15
- BOEING 737
- BOEING 767
- BOEING 747
- BOEING 777
- C-17
Changing the of the CBR Equation

![Reality Check for F-15](image1)

- \( n = \text{function of CBR} \)
- \( \alpha = 0.995 \)
- \( n = 2 \)

![Reality Check for 737](image2)

- \( n = \text{function of CBR} \)
- \( \alpha = 0.9 \)
- \( n = 2 \)

**F-15**

**Boeing 737**
Changing the of the CBR Equation

Reality Check for 767

Boeing 767

Reality Check for 747-400

Boeing 747
Changing the \( n \) of the CBR Equation

**Reality Check for 777**

- \( n = \text{function of CBR} \)
- \( \alpha = 0.788 \)
- \( n = 2 \)
- \( \alpha = 0.72 \)

**Boeing 777**

**Reality Check for C-17**

- \( n = \text{function of CBR} \)
- \( \alpha = 0.788 \)
- \( n = 2 \)
- \( \alpha = 0.72 \)

**C-17**
COMPARE CBR METHOD ($n=f(CBR)$ AND $\beta = 8.1$) with LAYER ELASTIC METHOD

- FOR BOEING 747
- FOR BOEING 777
Changing the of the CBR Equation
Changing the Equation of the CBR

Comparing thickness requirements for Boeing 747 and Boeing 777 as computed with layer elastic method and new CBR method ($n=f(CBR)$).

**Boeing 747**

**Boeing 777**
What will be gained?

- The CBR method will be retained
- The design criteria becomes visible
- The procedure becomes more mechanistic
- A direct procedure for handling multi-wheel tire groups without the ESWL
- Will eliminate the need for $\alpha$